The Association between Ideal Cardiovascular Health and Risk of Sudden Cardiac Death and All-cause Mortality Among Finnish Middle-aged Men

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Abstract

Background: Strong associations between American Heart Association's cardiovascular health (CVH) metrics and various cardiovascular outcomes have been demonstrated, but the association with sudden cardiac death (SCD) is uncertain. We sought to examine the associations between the CVH metrics and the risks of SCD and all-cause mortality among men.

Methods and results: We utilized the prospective population-based Kuopio Ischaemic Heart Disease cohort study comprising of men between 42 to 60 years at baseline. CVH metrics were computed for 2577 men at baseline with CVH scores ranging from 0 to 7, categorized into: '0 – 2' (Poor), '3 – 4' (Intermediate) and '5 -7' (Ideal) CVH scores. Multivariate Cox regression models were used to estimate hazard ratios (HRs) and 95% confidence intervals (CIs) of ideal CVH metrics for SCD and all-cause mortality. During a median follow-up period of 25.8 years, 280 SCDs and 1289 all-cause mortality events were recorded. The risks of SCD and all-cause mortality decreased continuously with increasing number of CVH metrics across the range 2-7 (*p*-value for nonlinearity for all<0.05). In multivariable analyses, men with ideal CVH score had 85% reduced risk of SCD when compared with those with poor CVH score (HR: 0.15; 95% CI: 0.05 – 0.48, *p* =0.001). For all-cause mortality, there was a 67% lower risk among men with ideal CVH score compared with those with poor CVH score (HR: 0.33; 95% CI: 0.23 – 0.49, *p* <0.001).

Conclusion: Ideal CVH metrics was strongly and linearly associated with the decreased risks of SCD and all-cause mortality among middle-aged men.

Abstract word count: 250

Keywords: Cardiovascular health metrics; sudden cardiac death; all-cause mortality; risk factors; men

Introduction

Sudden cardiac death (SCD) accounts for about half of deaths from cardiovascular disease (CVD) [1]. Death certificate data has estimated 15% of all deaths in the western countries are caused by SCD [2]. Common CVD risk factors may contribute to SCD development and risk stratification techniques can help identify individuals at risk of SCD, however, effective prevention is challenging [2].

A decade ago, the American Heart Association (AHA) developed metrics for ideal cardiovascular health (CVH), to assess the cardiovascular status of the population. The metrics focused on 7 cardiovascular–risk modifiable health behaviours and biological factors - smoking, body mass index (BMI), physical activity, diet, fasting blood glucose (FBG), total cholesterol and blood pressure [3]. Although several studies have established strong associations between the CVH metrics and various cardiovascular outcomes [4-6], there remains a dearth of literature available on the association between AHA's CVH metrics and the risk of SCD. To the best of our knowledge, no study has at yet evaluated the association between the CVH metrics and risk of SCD. Therefore, we aimed to evaluate the prospective relationship between ideal CVH metrics and risk of SCD and all-cause mortality among a middle-aged Finnish population.

Methods

Study population

This study employed the ongoing population-based Kuopio Ischemic Heart Disease (KIHD) study. The KIHD was initially designed to investigate the different risk factors for developing CVD and other chronic diseases among middle-aged men in Kuopio and the surrounding communities [7]. Briefly, the study commenced in 1984 with men randomly selected from the national population register, aged 42 to 60 years at baseline. Of the 3235 eligible men, 2682 volunteered to participate in this study. Women were included 11 years after the baseline examinations. The present analysis is based on the initial cohort

comprising of 2577 men with non-missing data on ideal CVH metrics, relevant covariates and SCD. The research protocol (KIHD) was approved by the Research Ethics Committee of the University of Eastern Finland, Kuopio with reference number 143/97. The study protocol conforms to the ethical guidelines of the Declaration of Helsinki. All participants included in the study gave an informed consent.

Data collection

A self-administered questionnaire was mailed to each participant prior to their visit to the study centre. The participants were then invited to the study centre for interviews and clinical examination. A trained research nurse was responsible for interviewing all the study participants, who also went through a health examination. Details of the assessment for the blood pressure (BP), BMI, nutritional status, smoking status, alcohol consumption, physical activity, prevalent medical conditions and socioeconomic status (SES) have previously been discussed [6]. The SES scale ranges from 0 through 25; 0 indicating the highest, and 25 the lowest SES.

Laboratory methods

Participants provided blood specimens between the hours of 8 and 10 in the morning following abstinence from alcohol ingestion for 3 days, smoking for 12 hours and eating for 12 hours. After the subject had rested for 30 minutes in the supine position, blood sample was drawn from the antecubital vein with Terumo Venoject VT-100PZ vacuum (Terumo Corp., Tokyo), without the use of tourniquet. The cholesterol contents of serum lipoprotein fractions and triglycerides were measured enzymatically (Boehringer Mannheim). Serum high-density lipoprotein cholesterol (HDL-C) and its subfractions were separated from fresh serum samples using ultracentrifugation and precipitation. Blood glucose was measured by glucose dehydrogenase method (Merck, Darmstadt, FRG) after precipitation of proteins by trichloric acetic acid [8].

Cardiovascular Health Metrics

The CVH metrics adopted in this study was in conformity with the CVH metrics developed by AHA, consisting of 7 health behavioural and biological factors including healthy diet score (HDS), physical activity, BMI, smoking status, BP, fasting blood glucose and plasma total cholesterol [3, 6] (**Supplementary Table 1**). Thus, the ideal CVH metric consists of: 1) HDS of 4 - 5, i.e. 4 to 5 components of the following: ≥4.5 cups/day of fruits and vegetables, ≥two 3.5-ounce servings/week of fish, <1,500mg/day of sodium, ≤ 36ounces/week of sweets/sugars and ≥ three 1-ounce servings/day of whole grains. The salt intake for this study was substituted with intake of processed meat, which has been demonstrated to contain much salt (sodium) [9]; 2) physical activity: ≥150minutes/week moderate-intensity physical activity (MET 3-6) or ≥75 minutes/week of vigorous intensity aerobic physical activity (MET >6) or equivalent combination; 3) smoking status: never smoked; 4) BMI: <25 kg/m^2; 5) blood pressure: <120/<80 mmHg; 6) FBG: <5.55 mmol/l; and 7) total cholesterol: < 5.18 mmol/l.

Ascertainment of sudden cardiac death and all-cause mortality outcomes

SCD was defined as death that occurred within 1 hour of the onset of an abrupt change in symptoms or within 24 hours after the onset of symptoms when clinical findings did not reveal a noncardiac cause of sudden death. Deaths that occurred unwitnessed during the night, such as being found dead in bed, were classified as those whose death occurred 24 hours from the symptoms. Patients who were successfully resuscitated from ventricular tachycardia and/or ventricular fibrillation were also defined. The deaths due to aortic aneurysm rupture, cardiac rupture or tamponade, and pulmonary embolism, cancer, or other noncardiac co-morbidities were not included as SCDs. The diagnostic classification of events was based on symptoms, electrocardiographic (ECG) findings, cardiac enzyme elevations, autopsy findings (80%), and history of coronary heart disease, together with the clinical and ECG findings of the paramedic staff. Out-of-hospital SCDs and non-SCDs were documented. All hospital documents, including medical records, laboratory, and ECG findings from hospital and paramedical staff, and the use of medications and defibrillators, were available to use [10, 11]. All deaths that occurred by the end of 2014 were checked against the hospital documents, health center wards, and death certificates. There were no losses to follow-up. All

the documents related to the death were crosschecked in detail by 2 physicians. The Independent Events Committee, masked to clinical data, performed classification of deaths. Censoring was done on the date from the baseline visit to first SCD development, death, loss to follow-up, or end of observation (31.12.2014).

Statistical analysis

The baseline characteristics of the participants were summarized using descriptive statistics, presented as means (standard deviation) or median (interquartile range) for continuous variables, and for categorical variables, in number (percentages). We explored the shape of the relationship between CVH metrics (as a continuous variable) and risk of outcomes using restricted cubic splines with knots at the 5th, 35th, 65th and 95th percentiles of CVH metrics distribution in a multivariate adjusted model. Multivariate Cox regression models were used to estimate the hazard ratios (HRs) and 95% confidence intervals (CIs) of SCD and all-cause mortality for baseline ideal CVH metrics, behavioural and biological health factors, after confirmation of no major departure from the proportionality assumptions using Schoenfeld residuals [12]. The CVH metrics was dichotomized, with a score of 1 given for every ideal component, and 0 for poor and intermediate components, generating a CVH score ranging from 0 to 7. The 7 scores were categorized into 3 groups: '0 – 2' (Poor), '3 – 4' (Intermediate), and '≥5' (Ideal) CVH; and CVH score of '0 – 2' was used as the referent. Also, based on the ideal components of the 2 factors that constitute CVH metrics – the behavioural (physical activity, smoking, BMI and HDS), and biological health factors (blood pressure, fasting blood glucose and total cholesterol), health scores of '0, 1, 2, ≥3' and '0, 1, 2, 3' were generated respectively, with '0' score as referent.

Hazard ratios were calculated with adjustment in 2 models: i) model 1: age, alcohol consumption and SES; ii) model 2: model 1 plus history of coronary heart disease (CHD) and history of type 2 diabetes mellitus. These covariates were selected based on previously established roles as risk factors and potential confounders, taking into consideration factors in the CVH metrics. All statistical analyses were performed

using Microsoft windows software, IBM SPSS Statistics 25. Two-sided *p* value <0.05 was considered statistically significant.

Results

Baseline characteristics

Characteristics of the study participants are shown in **Table 1**. During a median follow-up year of 25.8 years, 280 cases of SCD and 1289 all-cause deaths were recorded. The mean age at baseline for the 2577 men was 53 years. Only 1 person achieved all the 7 ideal metrics at baseline (**Supplementary Table 2**). Most of the participants (91.9%) were in the ideal FBG category. No participant with all behavioural health score of 4 had a SCD event.

CVH metrics and risk of SCD and all-cause mortality

A restricted cubic spline curve showed that the risk of SCD decreased continuously with increasing CVH metrics across the range 2-7 (*p*-value for nonlinearity=0.54) (**Fig. 1**). In **Table 2, t**he association between CVH scores and risk of SCD shows that men who attained ≥5 CVH score had 85% reduced risk of SCD when compared with those with '0 to 2' CVH score (HR: 0.13; 95%CI: 0.03 – 0.53, $p = 0.004$) after adjustment for age, alcohol consumption and SES. The association was minimally attenuated on further adjustment for history of CHD and history of type 2 diabetes mellitus (model 2). Achieving ≥3 behavioural health score showed a significant relationship with risk of SCD, when compared to those with score of 0 (HR: 0.20; 95%CI: 0.10 – 0.41, $p < 0.001$). Similar significant association was observed with biological health scores.

For the association between CVH score and risk of all-cause mortality, the risk of all-cause mortality decreased continuously with increasing CVH scores across the range 2-7 (*p*-value for nonlinearity=0.16) (**Fig. 2**). Men who had a minimum of 5 CVH score were at 67% lower risk, compared with those with '0 to 2' CVH score, after adjustments for age, alcohol consumption and SES (**Table 2**). Ideal behavioural factor also showed significant association among men who achieved at least 3

behavioural health scores having 70% lower risk of all-cause mortality when compared with those with '0' score (HR: 0.30; 95%CI: 0.22 – 0.40, p <0.001). On sensitivity analysis excluding participants with a previous history of CHD at baseline, these association between CVH scores and risks of SCD and all-cause mortality remained statistically significant (**Supplementary Table 3**).

Analysis on the association of the individual components of CVH metrics and risks of SCD and all-cause mortality is shown in **Supplementary Table 4**. Ideal BMI is associated with 50% reduced risk of SCD. Specifically, ideal levels of BMI, smoking status, BP, FBG and total cholesterol contributed significantly to reduced risk of SCD. Men who achieved 3 or all 4 of ideal behavioural factors had 80% and 70% lower risks of SCD and all-cause mortality respectively, when compared with those with no ideal behavioural factors.

Discussion

In this prospective study of Finnish men and the first study to assess the association of AHA's CVH metrics and the risk of SCD among the general population, men with CVH score of 5 to 7 at baseline had 83% reduced risk of SCD after a median follow-up period of 25.8 years. Similarly, there was 65% lower risk of all-cause mortality among men with at least 5 CVH score when compared with those with '0 – 2' CVH score. The associations were consistent with linear dose-response relationships.

The distribution of ideal CVH metrics among the participants in our study is comparable to earlier studies. In our study, the most frequent metric was ideal FBG, similar to the People's Republic of China-USA (PRC-USA) Collaborative Study cohort [13]. Also, both the PRC-USA Collaborative study and our study have diet as the least frequent ideal metric. There are no similar studies on the association of AHA's CVH metrics and risk of SCD, but researchers have shown existing associations between ideal CVH and some cardiovascular outcomes and mortality [4, 14-17] . Thus, in the PRC-USA Collaborative study, 54% lower risk of all-cause mortality was observed among participants with 4 – 7 ideal metrics, when compared with those with 0 – 2 [13]. Similar findings are demonstrated in the Northern Manhattan study and

Three City study [4, 18], and summarized in a recent meta-analysis of prospective studies[16]. Our findings are consistent with the existing evidence on the association of ideal CVH and risk of all-cause mortality.

Obesity, smoking, hypertension and diabetes have been identified as risk factors for SCD, and vigorous physical activity can increase the risk of SCD [10, 19]. Our current study demonstrates similar pattern of association (**Supplementary Table 4**). It may not be surprising that ideal physical activity did not show an independent significant association with the risk of SCD when compared with those with poor physical activity since it incorporated vigorous physical activity (**Supplementary Table 1**), which might be a cause of sudden death [19-21]. The findings remained consistent after excluding men with a previous history of CHD at baseline.

The assessment for the applicability of AHA's CVH metrics among middle-aged Finnish men, who are at higher risks of death from diseases of the circulatory system,[22] reveals that the metrics may be applicable to European populations and could be used for health promotion purposes to reduce CVD burden and future SCD risk, limiting the possible use of drugs or electrical devices for prevention purposes [23]. Thus, campaigns and policies that are aimed at improving CVH metrics should be encouraged. Health professionals can use this metrics to assess and identify people at risk of SCD and encourage early modification of CVH metrics to improve the quality of lives. To improve levels of behavioural factors, individuals can start from those factors which they can realistically control.

The strengths of this study lie in the relatively large number of participants, being a representative sample of middle-aged male population in Eastern Finland. They were well characterized and followed-up during the study period with well-documented outcome data. However, some limitations of this study warrant mentioning. First, the results are based on Finnish men, and therefore cannot be generalized to other population groups. Also, causality cannot be confirmed. Second, there could be misclassification bias given the use of self-administered questionnaires to obtain information on some of the components of the CVH metrics. Also, the substitution of the salt intake with the intake of processed meat might have some effect in the computation of the HDS in this study. However, in the Finnish diet and lifestyle

recommendations on the use of salt in the 1980s, the intake of preprocessed meats fall under the convenience foods to be avoided as they were among the sources of excess salt in the Finnish diet[24]. Third, given the long period of follow-up and the employment of baseline assessments, it is likely that the levels of CVH metrics may change over time. This could be due to some potential factors such as ageing, disease, modification of lifestyle and use of lipid-lowering and antihypertensive medications, thereby leading to the underestimation of true associations as a result of regression dilution bias. Therefore, it would be interesting to investigate further on how the longitudinal evolution of the CVH metrics or interventions to improve ideal CVH influences the rates of SCD and all-cause mortality.

In conclusion, baseline ideal CVH values was strongly and linearly associated with the future risks of SCD and all-cause mortality among Finnish men. Interventions that will help the population to step up towards achieving more ideal CVH metrics levels should be emphasized and embraced as a wide-scale health promotion tool that can reduce SCDs and improve CVH in the general population.

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Declaration of conflicting interests

The authors declare that there is no conflict of interest.

Authors' contributions

NI, SKK and JL contributed to the conception and design as well as the acquisition, analysis and

interpretation of the work. AV contributed to the acquisition and analysis for the work. SK and JK contributed to the acquisition of the work. NI drafted the manuscript. All critically revised the manuscript and gave final approval and agree to be accountable for all aspects of work ensuring integrity and accuracy.

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Figure titles and legends

Figure 1. Restricted cubic curve of hazard ratio for sudden cardiac death (SCD) against cardiovascular health (CVH) metrics

Restricted cubic spline functions were analysed with knots located at 5th, 35th, 65th and 95th percentiles of CVH distribution, with the reference category set at 2; adjusted for age, alcohol consumption, socioeconomic status, history of coronary heart disease and history of type 2 diabetes mellitus. The dashed lines represent the 95% confidence intervals

Figure 2. Restricted cubic curve of hazard ratio for all-cause mortality against cardiovascular health (CVH) metrics

Restricted cubic spline functions were analyzed with knots located at 5th, 35th, 65th and 95th percentiles of CVH distribution, with the reference category set at 2; adjusted for age, alcohol consumption, socioeconomic status, history of coronary heart disease and history of type 2 diabetes mellitus. The dashed lines represent the 95% confidence intervals

Supplementary Figure. Distribution of cardiovascular health (CVH) metrics

Table 1: Baseline characteristics and cardiovascular health scores in the KIHD cohort

Characteristics (mean [SD] or median [IQR] or number [%])	All Participants N, 2577	Men without sudden cardiac death event N, 2297	Sudden cardiac death N, 280	All-cause mortality N, 1289	Cardiovascular health scores			*P* value*
					0 - 2 (N, 1140)	3 – 4 (N, 1299)	≥5 (N, 138)	
Age (years)	53.1 (5.1)	52.9 (5.2)	54.4 (4.2)	54.6 (4.3)	53.4 (4.9)	52.9 (5.3)	51.9 (5.7)	0.001
Socioeconomic status	12.3 (5.1)	12.1 (5.2)	13.4 (4.8)	13.4 (5)	13 (5.0)	11.9 (5.1)	10.0 (5.2)	<0.001
Alcohol/week (grams)	31.8 (6.3 – 91.6)	30.7 (6.2 – 89.2)	39.7 (7.3 – 112.9)	38 (6.4 – 115.5)	44 (9.3 – 118.4)	26.1 (4.6 – 80.0)	11.4 (1 – 36)	<0.001
History of coronary heart disease[a]	646 (25.1)	518 (22.6)	128 (45.7)	420 (32.6)	343 (30.1)	280 (21.6)	23 (16.7)	<0.001
History of diabetes mellitus[a]	151 (5.9)	117 (5.1)	34 (12.1)	116(9.0)	124 (10.9)	25 (1.9)	2 (1.4)	<0.001
Ideal CVH score	2.7 (1.1)	2.8 (1.1)	2.3 (1.0)	2.5 (1.0)	1.7 (0.5)	3.4 (0.5)	5.2 (0.4)	<0.001
Mean systolic blood pressure (mmHg)	134.1 (17.1)	133.5 (16.9)	139.7 (17.6)	136.6 (18.0)	138.4 (16.6)	132.1 (16.5)	118.6 (12.4)	<0.001
Smokers[a]	818 (31.7)	697 (30.3)	121 (43.2)	539 (41.8)	453 (39.7)	350 (26.9)	15 (10.9)	<0.001
Body mass index (kg/m^2)	26.9 (3.6)	26.8 (3.5)	28.1 (4.1)	27.3 (3.9)	28.4 (3.4)	25.9 (3.2)	23.5 (2.0)	<0.001
Total cholesterol (mmol/l)	5.9 (1.1)	5.9 (1.1)	6.1 (1.1)	6.0 (1.1)	6.2 (1.0)	5.7 (1.1)	4.9 (0.7)	<0.001

*Statistical significance for categorical variables tested using chi-squared method, and analysis of variance procedure for continuous variables; [a] Values presented as number (%)
Socioeconomic status was defined as a combined measure of income, education, occupation, occupational prestige, material standard of living and housing conditions. The scale ranges from 0 - 25; 0 indicating the highest, and 25 the lowest.

Table 2: Association of CVH score, behavioural and biological health scores and risk of SCD and all-cause mortality

	Sudden cardiac death					All-cause mortality				
	n/N 280/2577	Model 1		Model 2		n/N 1289/2577	Model 1		Model 2	
		HR (95%CI)	*P* value	HR (95%CI)	*P* value		HR (95%CI)	*P* value	HR (95%CI)	*P* value
CVH score										
0-2	162/1140	1		1		676/1140	1		1	
3-4	115/1299	0.61 (0.48 – 0.78)	<0.001	0.70 (0.55 – 0.90)	0.005	585/1299	0.74 (0.66 – 0.83)	<0.001	0.79 (0.70 – 0.88)	<0.001
≥5	3/138	0.15 (0.05 – 0.48)	0.001	0.17 (0.05 – 0.53)	0.002	28/138	0.33 (0.23 – 0.49)	<0.001	0.35 (0.24 – 0.52)	<0.001
Behavioural health scores										
0	46/271	1	-	1	-	177/271	1	-	1	-
1	135/1145	0.61 (0.43 – 0.85)	0.004	0.65 (0.47 – 0.91)	0.013	629/1145	0.72 (0.61 – 0.85)	<0.001	0.74 (0.62 – 0.87)	<0.001
2	90/933	0.52 (0.36 – 0.74)	<0.001	0.61 (0.42 - 0.87)	0.007	430/933	0.63 (0.53 – 0.75)	<0.001	0.67 (0.56 – 0.79)	<0.001
≥3	9/228	0.20 (0.10 – 0.41)	<0.001	0.24 (0.12 – 0.50)	<0.001	53/228	0.30 (0.22 – 0.40)	<0.001	0.32 (0.23 – 0.44)	<0.001
Biological health scores										
0	39/156	1	-	1	-	118/156	1	-	1	-
1	183/1598	0.35 (0.25 – 0.50)	<0.001	0.47 (0.30 – 0.72)	0.001	816/1598	0.49 (0.40 – 0.59)	<0.001	0.62 (0.49 – 0.79)	<0.001
2	53/729	0.23	<0.001	0.30	<0.001	321/729	0.43	<0.001	0.55	<0.001

		(0.15 – 0.35)		(0.18 – 0.50)			(0.35 – 0.53)		(0.43 – 0.71)	
3	5/94	0.18	<0.001	0.22	0.002	34/94	0.37	<0.001	0.47	<0.001
		(0.07 – 0.45)		(0.08 – 0.58)			(0.25 – 0.55)		(0.31 – 0.70)	

n/N, number of events/Total; HR, hazard ratio; CVH, cardiovascular health. Reference group to which the hazard ratios are compared are '0 to 2' for ideal CVH; and '0' for ideal behavioural and biological health factors

Model 1, Adjusted for age; alcohol consumption; socioeconomic status

Model 2, Model 1 plus history of coronary heart disease and history of type 2 diabetes mellitus.

Supplementary Table 1: Definition of cardiovascular health metrics

Cardiovascular health metrics	Poor	Intermediate	Ideal
Healthy diet score	0 – 1	2 – 3	4 – 5 components[a]
Physical activity	No physical activity	1-149 mins/week of moderate intensity physical activity or 1-74 mins/week of vigorous intensity or both	≥150minutes/week moderate intensity (MET 3-6) or ≥75 minutes/week of vigorous intensity (MET >6) or combination
Body mass index, kg/m^2	≥ 30	25 – 29.9	<25
Smoking status	Current smokers	Previous smokers	Never smoked
Blood pressure, mmHg	SBP ≥ 140 or DBP ≥ 90	SBP, 120 – 139 or DBP, 80 – 89	SBP <120 and DBP <80
Fasting blood glucose[b], mmol/l	≥7.00	5.55 – 6.99	<5.55
Plasma total cholesterol [c], mmol/l	≥ 6.22	5.18 -6.21	< 5.18

[a] The components are: ≥4.5 cups/day of fruits and vegetables, ≥two 3.5-ounce servings/week of fish, <1,500mg/day of sodium, ≤ 36ounces/week of sweets/sugars and ≥ three 1-ounce servings/day of whole grains; [b]mmol/l x 18 = mg/dl; [c]mmol/l x 38.6= mg/dl

DBP, diastolic blood pressure; MET, metabolic equivalent; mmHg, millimeter mercury; SBP, systolic blood pressure

Supplementary Table 2: Distribution of baseline cardiovascular health metrics by sudden cardiac death, all-cause mortality and age group

Cardiovascular Health (CVH) Metrics	All participants N, 2577 [a]	Sudden cardiac death N, 280	All-cause mortality N, 1289	Age categories (years)			
				≤45, N 321	>45 – 50, N 344	>50 – 55, N 1497	>55, N 415
Physical Activity							
Ideal	2014 (78.2)	211 (75.4)	970 (75.3)	262 (81.6)	280 (81.4)	1120 (74.8)	352 (84.8)
Intermediate	21 (0.8)	2 (0.7)	11 (0.8)	1 (0.3)	1 (0.3)	14 (0.9)	5 (1.2)
Poor	542 (21)	67 (23.9)	308 (23.9)	58 (18.1)	63 (18.3)	363 (24.3)	58 (14)
Body mass index							
Ideal	805 (31.2)	60 (21.4)	360 (27.9)	122 (38)	122 (35.5)	440 (29.4)	121 (29.2)
Intermediate	1326 (51.5)	140 (50)	657 (51)	150 (46.7)	173 (50.3)	784 (52.4)	219 (52.8)
Poor	446 (17.3)	80 (28.6)	273 (21.1)	49 (15.3)	49 (14.2)	273 (18.2)	75 (18.1)
Healthy Diet Score							
Ideal	50 (1.9)	4 (1.4)	28 (2.2)	5 (1.6)	8 (2.3)	27 (1.8)	10 (2.4)
Intermediate	1239 (48.1)	146 (52.1)	617 (47.9)	135 (42)	171 (49.7)	716 (47.8)	217 (52.3)
Poor	1288 (50)	130 (46.4)	644 (50)	181 (56.4)	165 (48)	754 (50.4)	188 (45.3)
Smoking Status							
Ideal	830 (32.2)	67 (23.9)	292 (22.7)	112 (34.9)	121 (35.2)	483 (32.3)	114 (27.5)
Intermediate	929 (36)	92 (32.9)	458 (35.5)	92 (28.7)	117 (34)	549 (36.7)	171 (41.2)
Poor	818 (31.7)	121 (43.2)	539 (41.8)	117 (36.4)	106 (30.8)	465 (31)	130 (31.3)
Blood Pressure							
Ideal	310 (12)	19 (6.8)	134 (10.4)	44 (13.7)	50 (14.5)	154 (10.3)	62 (14.9)
Intermediate	982 (38.1)	90 (32.1)	460 (35.7)	127 (39.6)	137 (39.9)	549 (36.7)	169 (40.8)
Poor	1285 (49.9)	171 (61.1)	695 (53.9)	150 (46.7)	157 (45.6)	794 (53)	184 (44.3)

FBG							
Ideal	2368 (91.9)	233 (83.2)	1133 (87.9)	303 (94.4)	320 (93)	1368 (91.4)	377 (90.8)
Intermediate	124 (4.8)	25 (8.9)	84 (6.5)	14 (4.4)	15 (4.4)	71 (4.7)	24 (5.8)
Poor	85 (3.3)	22 (7.9)	72 (5.6)	4 (1.2)	9 (2.6)	58 (3.9)	14 (3.4)
Total Cholesterol							
Ideal	660 (25.6)	52 (18.6)	293 (22.7)	87 (27.1)	102 (29.7)	359 (24)	112 (27)
Intermediate	1023 (39.7)	105 (37.5)	494 (38.4)	144 (44.9)	155 (44.7)	566 (37.8)	159 (38.3)
Poor	894 (34.7)	123 (43.9)	502 (38.9)	90 (28)	88 (25.6)	572 (38.2)	144 (34.7)
Ideal CVH metrics							
0	29 (1.1)	8 (2.9)	23 (1.8)	1 (0.3)	4 (1.2)	20 (1.3)	4 (1)
1	261 (10.1)	52 (18.6)	179 (13.9)	27 (8.4)	24 (7.0)	180 (12)	30 (7.2)
2	850 (33)	102 (36.4)	474 (36.8)	88 (27.4)	108 (31.4)	509 (34)	145 (34.9)
3	834 (32.4)	85 (30.4)	400 (31)	119 (37.1)	100 (29.1)	474 (31.7)	141 (34)
4	465 (18)	30 (10.7)	185 (14.4)	61 (19)	80 (23.3)	251 (16.8)	73 (17.6)
5	115 (4.5)	3 (1.1)	25 (1.9)	20 (6.2)	25 (7.2)	51 (3.4)	19 (4.6)
6	22 (0.9)	-	3 (0.2)	4 (1.2)	3 (0.9)	12 (0.8)	3 (0.7)
7	1 (0)	-	-	1 (0.3)	-	-	-
Behavioural health scores							
0	271 (10.5)	46 (16.4)	177 (13.7)	26 (8.1)	30 (8.7)	181 (12.1)	34 (8.2)
1	1145 (44.4)	135 (48.2)	629 (48.8)	130 (40.5)	138 (40.1)	684 (45.7)	193 (46.5)
2	933 (36.2)	90 (32.2)	430 (33.4)	126 (39.3)	136 (39.6)	511 (34.1)	160 (38.6)
3	224 (8.7)	9 (3.2)	51 (4)	37 (11.5)	40 (11.3)	120 (8)	28 (6.7)
4	4 (0.2)	-	2 (0.2)	2 (0.6)	1 (0.3)	1 (0.1)	-
Biological health scores							
0	156 (6.1)	39 (13.9)	118 (9.2)	14 (4.4)	17 (4.9)	103 (6.9)	22 (5.3)

1	1598 (62)	183 (65.4)	816 (63.3)	196 (61.1)	198 (57.6)	949 (63.4)	255 (61.4)
2	729 (28.3)	53 (18.9)	321 (24.9)	95 (29.6)	113 (32.8)	403 (26.9)	118 (28.4)
3	94 (3.6)	5 (1.8)	34 (2.6)	16 (5)	16 (4.7)	42 (2.8)	20 (4.8)

[a] Values presented as number (%), FBG, fasting blood glucose, CVH, cardiovascular health

Definitions of ideal, intermediate and poor, as in Supplement Table 1.

Supplementary Table 3: Association of CVH scores, behavioural and biological health factors and risk of SCD and all-cause mortality in men without previous history of CHD

	Sudden cardiac death					All-cause mortality				
	n/N	Model 1		Model 2		n/N	Model 1		Model 2	
	152/1931	HR (95%CI)	*P* value	HR (95%CI)	*P* value	869/1931	HR (95%CI)	*P* value	HR (95%CI)	*P* value
CVH score										
0-2	82/797	1	-	1	-	421/797	1	-	1	-
3-4	69/1019	0.67 (0.48 – 0.93)	0.02	0.70 (0.50 – 0.97)	0.03	427/1019	0.79 (0.69 – 0.91)	<0.01	0.82 (0.72 – 0.94)	0.01
≥5	1/115	0.09 (0.01 – 0.68)	0.02	0.10 (0.01 – 0.72)	0.02	21/115	0.38 (0.25 – 0.59)	<0.01	0.40 (0.26 – 0.63)	<0.01
Behavioural health score										
0	21/177	1	-	1	-	104/177	1	-	1	-
1	66/819	0.60 (0.36 – 0.98)	0.04	0.60 (0.37 – 0.98)	0.04	404/819	0.73 (0.59 – 0.90)	<0.01	0.72 (0.58 – 0.90)	<0.01
2	58/736	0.63 (0.38 – 1.03)	0.07	0.63 (0.38 – 1.04)	0.07	316/736	0.67 (0.53 – 0.83)	<0.01	0.67 (0.53 – 0.83)	<0.001
≥3	7/199	0.28 (0.12 – 0.67)	<0.01	0.29 (0.12 – 0.70)	0.01	45/199	0.35 (0.25 – 0.50)	<0.01	0.36 (0.26 – 0.52)	<0.001
Biological health score										
0	17/93	1	-	1	-	62/93	1	-	1	-
1	105/1212	0.42 (0.25 – 0.72)	<0.01	0.50 (0.26 – 0.95)	0.03	565/1212	0.61 (0.46 – 0.80)	<0.01	0.84 (0.61 – 1.16)	0.30
2	30/559	0.27 (0.15 – 0.51)	<0.01	0.32 (0.16 – 0.66)	<0.01	223/559	0.54 (0.41 – 0.72)	<0.01	0.75 (0.54 – 1.05)	0.10

3	0/67	-	-	-	-	19/67	0.41 (0.24 – 0.68)	<0.01	0.58 (0.33 – 1.00)	0.05

n/N, number of Events/Total; HR, hazard ratio; CVH, cardiovascular health. Reference group to which the hazard ratios are compared are '0 to 2' for ideal CVH; and '0' for ideal behavioural and biological health factors

Model 1, Adjusted for age; alcohol consumption; socioeconomic status

Model 2, Model 1 plus history of type 2 diabetes mellitus

Supplementary Table 4: HRs of intermediate and ideal CVH metrics for SCD and all-cause mortality: Analysis by Metric

	Sudden cardiac death				All-cause mortality			
	n/N	HR [a] (95%CI)	HR [b] (95%CI)	*P* value for trend*	n/N	HR [a] (95%CI)	HR [b] (95%CI)	*P* value for trend*
Physical Activity				0.216				<0.001
Poor	67/542	1	1		308/542	1	1	
Intermediate	2/21	0.64 (0.16 – 2.60)	0.49 (0.12 – 2.01)		11/21	0.76 (0.42 – 1.39)	0.67 (0.37 – 1.23)	
Ideal	211/2014	0.79 (0.60 – 1.04)	0.82 (0.62 – 1.08)		970/2014	0.78 (0.68 – 0.89)	0.79 (0.70 – 0.90)	
Body mass index				<0.001				<0.001
Poor	80/446	1	1		272/446	1	1	
Intermediate	140/1326	0.56 (0.42 – 0.74)	0.61 (0.46 – 0.80)		657/1326	0.76 (0.66 – 0.87)	0.79 (0.69 – 0.91)	
Ideal	60/805	0.42 (0.30 – 0.59)	0.50 (0.35 – 0.70)		360/805	0.74 (0.63 – 0.87)	0.80 (0.69 – 0.94)	
Healthy Diet Score				0.316				0.812
Poor	130/1288	1	1		644/1288	1	1	
Intermediate	146/1239	1.19 (0.94 – 1.50)	1.13 (0.89 – 1.43)		617/1239	1.01 (0.90 – 1.13)	0.99 (0.88 – 1.10)	
Ideal	4/50	0.91 (0.34 – 2.47)	0.84 (0.31 – 2.29)		28/50	1.35 (0.92 – 1.97)	1.28 (0.88 – 1.87)	
Smoking Status				<0.001				<0.001

Poor	121/818	1	1		539/818	1	1	
Intermediate	92/929	0.56	0.54		458/929	0.60	0.60	
		(0.42 – 0.74)	(0.41 – 0.72)			(0.53 - 0.68)	(0.52 – 0.68)	
Ideal	67/830	0.45	0.48		292/830	0.42	0.43	
		(0.33 – 0.62)	(0.35 – 0.65)			(0.36 – 0.49)	(0.37 – 0.50)	
Blood Pressure				<0.001				<0.001
Poor	171/1285	1	1		695/1285	1	1	
Intermediate	90/982	0.67	0.71		460/982	0.84	0.88	
		(0.52 – 0.87)	(0.55 – 0.92)			(0.75 – 0.94)	(0.78 – 0.99)	
Ideal	19/310	0.48	0.47		134/310	0.82	0.84	
		(0.30 – 0.76)	(0.29 – 0.76)			(0.68 – 0.99)	(0.69 – 1.01)	
Fasting blood glucose				<0.001				<0.001
Poor	22/85	1	1		72/85	1	1	
Intermediate	25/124	0.56	0.65		84/124	0.54	0.58	
		(0.31 – 1.00)	(0.31 – 1.34)			(0.39 – 0.74)	(0.39 – 0.85)	
Ideal	233/2368	0.24	0.30		1133/236	0.32	0.35	
		(0.15 – 0.37)	(0.14 – 0.64)		8	(0.25 – 0.40)	(0.24 - 0.52)	
Total Cholesterol				<0.001				<0.001
Poor	123/894	1	1		502/894	1	1	
Intermediate	105/1023	0.80	0.79		494/1023	0.92	0.92	
		(0.62 – 1.04)	(0.61 – 1.03)			(0.82 – 1.05)	(0.81 – 1.04)	
Ideal	52/660	0.61	0.61		293/660	0.84	0.83	
		(0.44 – 0.85)	(0.44 – 0.84)			(0.73 – 0.97)	(0.72 – 0.96)	

n/N, number of Events/Total; HR, hazard ratio; CVH, cardiovascular health. The HRs and 95% CIs of each metric were estimated in separate Cox proportional hazard regression model. [a] HR adjusted for age, alcohol consumption, socioeconomic status. [b] HR adjusted for age, alcohol consumption and socioeconomic status, history of coronary heart disease and history of diabetes. The poor category was used as reference.

*Linear by linear association chi square statistics used to determine the trend

Definitions as in Supplement Table 1

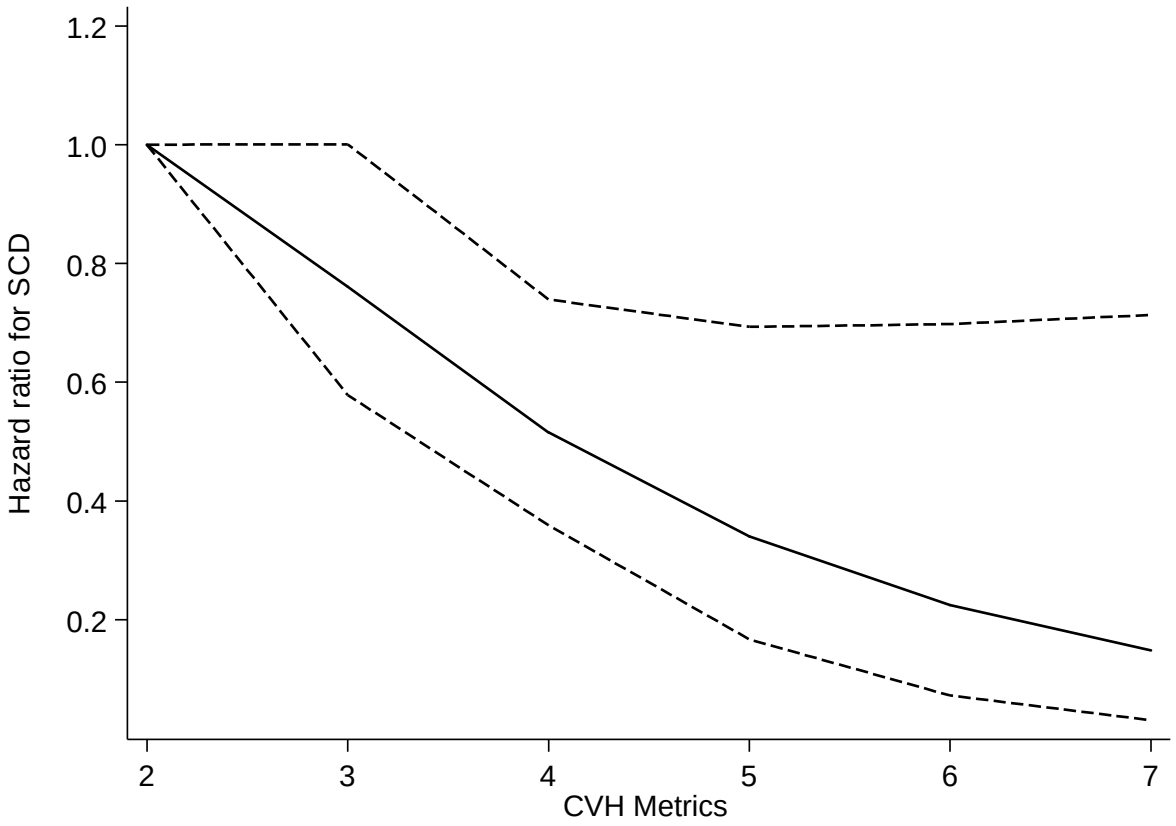


Fig. 1 Restricted cubic curve of hazard ratio for sudden cardiac death (SCD) against cardiovascular health (CVH) metrics

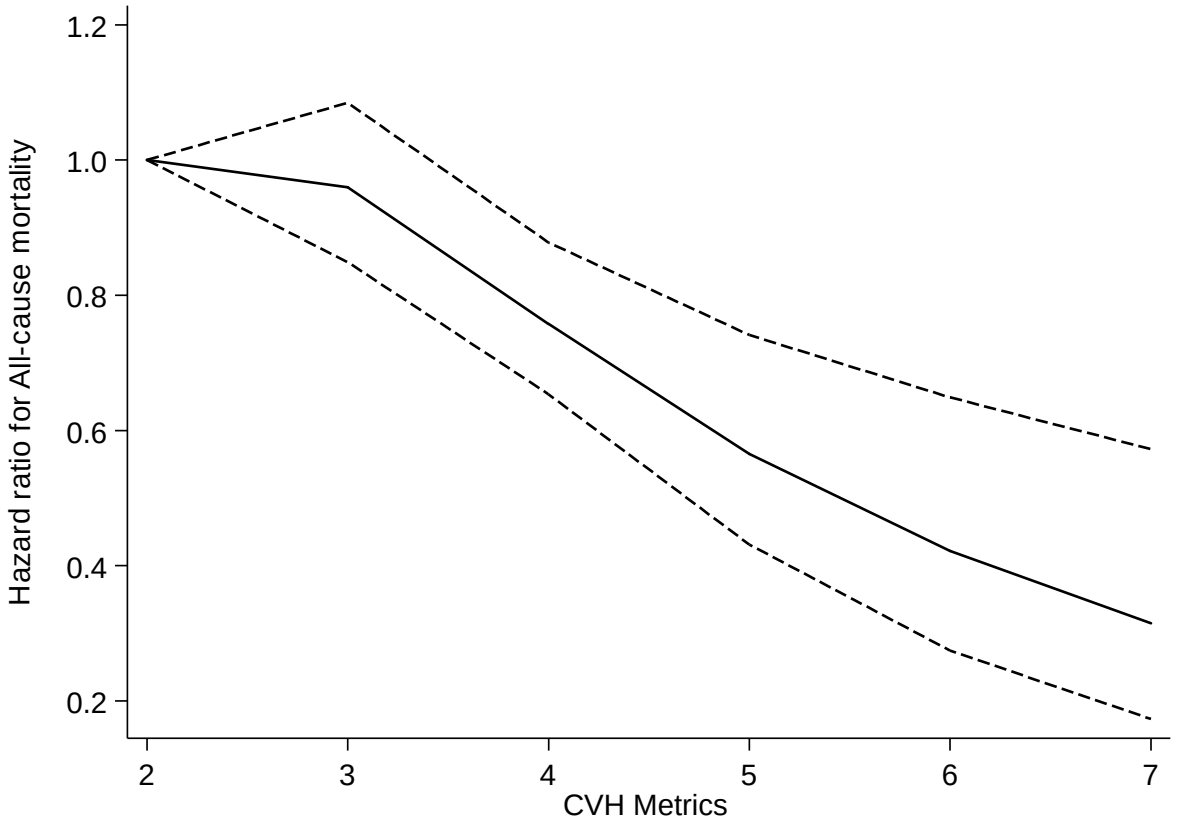
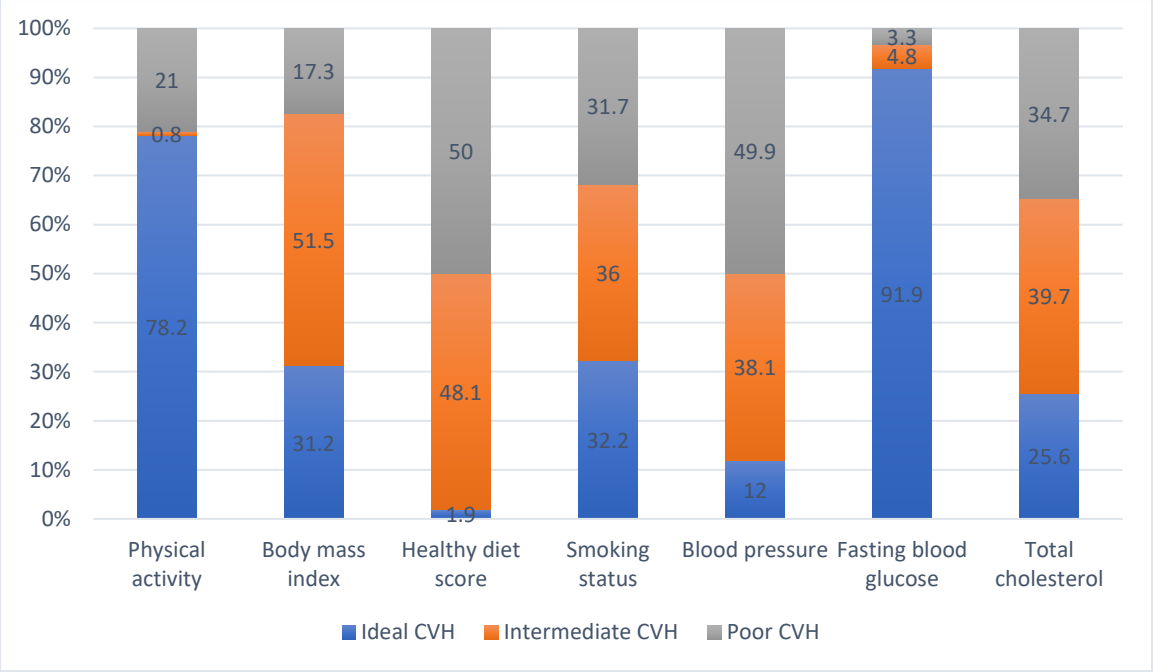


Fig. 2 Restricted cubic curve of hazard ratio for all-cause mortality against cardiovascular health (CVH) metrics



Supplementary Fig. Distribution of cardiovascular health (CVH) metrics